CLAIMS

We claim:

[c1] 1. A miniature resonating marker assembly, comprising

a core;

a wire coil disposed around the core;

a capacitor connected to the wire coil adjacent to the core to form a signal element that generates a magnetic field with a selected resonant frequency in response to a specific simulus, the magnetic field having a magnetic center along a first axis of the unit; and

an inert encapsulation member encapsulating the signal element, the encapsulation member and the signal element therein defining a unit having a selected geometric shape of the resonating marker assembly, the geometric shape having a geometric center, the geometric center being coincident with the magnetic center along at least the first axis of the unit.

[c2] 2. The miniature resonating marker assembly of claim 1 wherein the core is a material with a relative permeability greater than 1.0.

[c3] 3. The miniature resonating marker assembly of claim 1 wherein the core is a ferromagnetic core.

[c4] 4. The miniature resonating marker assembly of claim 1 wherein the core has a rod portion positioned within the coil and a pair of enlarged ferromagnetic endcaps connected to the rod portion, the endcaps having a relative permeability greater than 1, the coil being disposed between the endcaps.

[c5] 5. The miniature resonating marker assembly of claim 4 wherein the endcaps are made of a ferromagnetic material.

[c6] 6. The miniature resonating marker assembly of claim 4 wherein the endcaps each have an arcuate outer surface facing away from the rod portion.

[c7] 7. The miniature resonating marker assembly of claim 1 wherein the core has a rod portion positioned within the coil and a pair of enlarged endcaps connected to the rod, the coil being disposed between the endcaps, one of the endcaps having a volume of material greater than the volume of material of the other endcap.

[c8] 8. The miniature resonating marker assembly of claim 1 wherein the ferromagnetic core extends through the coil and has a first end portion exterior of one end of the coil and a second end portion exterior of another end of the coil, the first end portion exterior of the coil having a volume greater than the volume of the second end portion so the magnetic center is spaced apart from a center point of the coil.

[c9] 9. The miniature resonating marker assembly of claim 1 wherein the core has a rod portion positioned in the coil, a first endcap connected to one end portion of the rod portion, and a second endcap connected to another end portion of the rod, the first endcap being larger than the second endcap.

[c10] 10. The miniature resonating marker assembly of claim 1 wherein the core has a rod portion positioned in the coil, a first endcap connected to an end portion of the rod portion, and a second endcap connected to another end portion of the rod, the first endcap being axially adjustable over the rod portion and relative to the coil.

[c11] 11. The miniature resonating marker assembly of claim 10 wherein second endcap is fixed relative to the rod portion.

[c12] 12. The miniature resonating marker assembly of claim 1 wherein the geometric center is coincident with the magnetic center along three axis of the unit.

[c13] 13. The miniature resonating marker assembly of claim 1, further comprising a sleeve positioned between the wire coil and the core, the wire coil being wound onto the sleeve, and the sleeve and coil being positioned over the core as a unit.

[c14] 14. The miniature resonating marker assembly of claim 13 wherein the core is disposed within the sleeve and axially movable relative to the coil to achieve a selected resonant frequency of the assembly.

[c15] 15. The miniature resonating marker assembly of claim 1, further comprises a ferromagnetic adhesive securely retaining the coil on the core.

[c16] 16. The miniature resonating marker assembly of claim 1 wherein the wire coil includes a plurality of windings of a wire, the wire having a bonding coating thereon to adhere the wire of one wind to the wire of an adjacent wind.

[c17] 17. The miniature resonating marker assembly of claim 1 wherein the unit is attached to an anchoring member extending from one end of the unit and shaped to anchor the unit to tissue in or on a patient.

[c18] 18. The miniature resonating marker assembly of claim 1 wherein the assembly has an axial length of approximately 14 mm or less.

[c19] 19. A miniature resonating marker assembly having a geometric center, comprising:

a core having an elongated central portion and first and second endcaps attached to the central portion, the first endcap having an axial thickness difference from the second endcap to define an asymmetric core along at least one axis through the core;

a wire coil disposed around the central portion of the core between the first and second endcaps; and

a capacitor connected to the wire coil adjacent to the core to form a signal element that generates a magnetic field with a selected resonant frequency in response to a specific stimulus, the magnetic field having a magnetic center along a first axis of the unit, the magnetic center being coincident with the geometric center of the resonating marker assembly.

[c20] 20. A resonating marker assembly having a geometric center, comprising:

a ferromagnetic core having an elongated central portion and first and second ferromagnetic endcaps attached to the central portion, the core being substantially symmetrical about a longitudinal axis of the core, and being asymmetrical about a lateral axis of the core;

a wire coil disposed around the central portion of the ferromagnetic core intermediate the first and second endcaps; and

a capacitor connected to the wire coil adjacent to the ferromagnetic core to form a signal element that generates a magnetic field with a selected resonant frequency in response to a specific stimulus, the magnetic field having a magnetic center along a first axis of the unit, the magnetic center being coincident with the geometric center of the resonating marker assembly.

[c21] 21. A resonating marker assembly having a geometric center, comprising

a core having an elongated central portion and first and second endcaps connected to the central portion, the first endcap being axially movable relative to the central portion;

a wire coil disposed around the central portion of core intermediate the first and second endcaps; and

a capacitor connected to the wire coil adjacent to the core to form a tuned signal element that generates a magnetic field with a selected resonant frequency in response to a specific stimulus, the first endcap being movable relative to the coil and capacitor for tuning the marker assembly to a selected resonant frequency.

[c22] 22. A resonating marker assembly, comprising:

a sleeve;

a core having a central portion extending through the sleeve and a pair of endcaps connected to the central portion, the sleeve being between the endcaps and the core being axially movable relative to the sleeve;

a wire coil disposed around the sleeve; and

a capacitor connected to the wire coil adjacent to the core to form a signal element that generates a magnetic field with a selected resonant frequency in response to a specific stimulus, the core being axially movable relative to the sleeve and the coil for tuning the marker assembly to a selected resonant frequency.

[c23] 23. A tunable, resonating marker assembly, comprising:

a wire coil defining an interior area;

a capacitor connected to the wire coil to form an electrical circuit; and

a ferromagnetic core adjacent to the capacitor, the core having first and second segments each extending at least partially into the interior area of the coil, the first and second segments being axially movable relative to each other and to the coil for tuning the marker assembly to a selected resonant frequency.

[c24] 24. A resonating marker assembly, comprising:

a ferromagnetic core having an end portion with a recess formed therein;

a wire coil disposed around the ferromagnetic core; and

a capacitor positioned in the recess in the core's end portion and operatively connected to the wire coil adjacent to the ferromagnetic core to form a signal element that generates a magnetic field with a selected resonant frequency in response to a specific stimulus.

[c25] 25. A resonating marker assembly, comprising:

a core having a central portion intermediate to a pair of enlarged endcaps, the central portion having a first magnetic permeability and the enlarged endcaps having a second magnetic permeability different than the first magnetic permeability;

a wire coil disposed around the core intermediate to the endcaps;

a capacitor positioned in the recess in the core's end portion and operatively connected to the wire coil adjacent to the core to form a signal element that generates a magnetic field with a selected resonant frequency in response to a specific stimulus; and

an inert encapsulation member encapsulating the core, the wire coil, and the capacitor forming an activatable unit implantable in a patient through an introducer needle.

[c26] 26. A resonating marker assembly, comprising;

a capacitor having an aperture therethrough;

an elongated ferromagnetic core extending through the aperture in the capacitor;

a wire coil connected to the capacitor, the wire coil having a first portion disposed around the core adjacent to one side of the capacitor, and a second portion disposed around the core adjacent to another side of the capacitor; and

an inert encapsulation member encapsulating the capacitor, the core, and the coil.

[c27] 27. A resonating marker assembly, comprising:

an elongated core having an I-shaped cross-sectional area defined by a central web portion intermediate a pair of flange portions connected to the central web portion;

a wire coil disposed around the central web portion between the flange portions of the core;

a capacitor connected to the wire coil adjacent to the core to form a signal element that generates a magnetic field with a selected resonant frequency in response to a specific stimulus; and

an inert encapsulation member encapsulating the signal element forming an inert implantable, activatable marker assembly.

[c28] 28. A method of actively tuning a resonating marker assembly to have a selected resonant frequency value, comprising:

winding an elongated wire around a central portion of a ferromagnetic core intermediate a pair of ferromagnetic endcaps of the core to form a coil with a plurality of windings, the coil and core forming a combination with a first inductance value;

measuring the first inductance value of the combination;

comparing the first inductance to the selected inductance value; and

adjusting the amount of wire forming the coil after comparing the first inductance value to the selected inductance value by adding or removing one or more turns from the coil until the inductance value of the combination is substantially equal to the selected inductance value.

[c29] 29. A method of tuning a miniature resonating marker assembly to a selected resonant frequency, comprising:

placing a ferromagnetic core within a wire coil having a plurality of windings to form an inductor;

connecting lead wires of the inductor to a capacitor, the capacitor being adjacent to the core to form a miniature signal element;

exciting the marker assembly at a known frequency;

measuring the marker signal intensity or signal phase at the frequency of interest; and adjusting the core axially relative to the windings to adjust the actual inductance until the resonant frequency of the marker matches the desired frequency.

[c30] 30. A method of tuning a miniature resonating marker assembly to a selected resonant frequency where the impedance of the inductor and capacitor are matched at a selected resonant frequency, comprising:

placing a core within a wire coil having a plurality of windings

connecting lead wires of the inductor to a capacitor with the known capacitance, the capacitor being adjacent to the core to form a miniature signal element;

measuring the actual resonant frequency of the signal element;

comparing the actual resonant frequency of the signal element to the selected resonant frequency; and

adjusting the core axially relative to the winding to adjust the actual resonant frequency until the actual resonant frequency is substantially equal to the selected resonant frequency.

[c31] 31. The method of claim 30, further comprising fixing the core to the winding to prevent axial movement therebetween after the actual resonant frequency is substantially equal to the selected resonant frequency.

[c32] 32. The method of claim 30, further comprising winding the coil onto a sleeve with an interior area, and placing the core within the wire coil including placing the core within the interior area of the sleeve.

[c33] 33. The method of claim 30, further comprising encapsulating the core, the coil, and the capacitor in an inert encapsulation member, and sealing the encapsulation member to hermetically contain the tuned marker assembly.

[c34] 34. The method of claim 30 wherein the core includes a central portion within the coil and a pair of endcaps, and further comprising positioning an endcap on an end portion of the core's central portion adjacent to the coil, and adjusting the core axially including moving one of the endcaps axially on the central portion relative to the coil.

[c35] 35. The method of claim 30, further comprising securing the endcap on the core's central portion in a fixed location after the resonant frequency is substantially equal to the selected resonant frequency.

[c36] 36. The method of claim 30, further comprising forming the wire coil from a plurality of turns of a wire with an airbondable coating thereon to adhere each turn to one or more adjacent turns forming a self supporting winding.

[c37] 37. The method of claim 30, further comprising securing the core in a fixed position relative to the winding with a ferromagnetic -based adhesive when the actual resonant frequency is substantially equal to the selected resonant frequency.

[c38] 38. A method of making a tuned, miniature resonating marker assembly with a selected inductance, a known capacitance, and a selected resonant frequency comprising:

placing a wire coil around a ferromagnetic core having a central portion within the coil and a pair of ferromagnetic endcaps attached to the central portion adjacent to the coil;

connecting a capacitor to lead wires of the wire coil, the capacitor having a known capacitance and being adjacent to the core, the coil, and the capacitor to form an activatable assembly;

measuring the actual impedance and phase of the activatable assembly;

comparing the actual resonant frequency to the selected resonant frequency; and

removing ferromagnetic material from the core to adjust the actual resonant frequency of the activatable assembly until the actual resonant frequency is substantially equal to the selected resonant frequency.

[c39] 39. A method of tuning a miniature resonating marker assembly to a selected resonant frequency, comprising:

placing a ferromagnetic core within a wire coil having a plurality of windings to form an inductor;

connecting lead wires of the inductor to a capacitor, the capacitor being adjacent to the core to form a miniature signal element;

exciting the marker assembly at a known frequency;

measuring the marker signal intensity or signal phase at the frequency of interest; and

removing ferromagnetic material from the core to adjust the actual inductance of the activatable assembly until the resonant frequency of the marker matches the desired frequency.